Proton CT-based planning in the presence of dental implants

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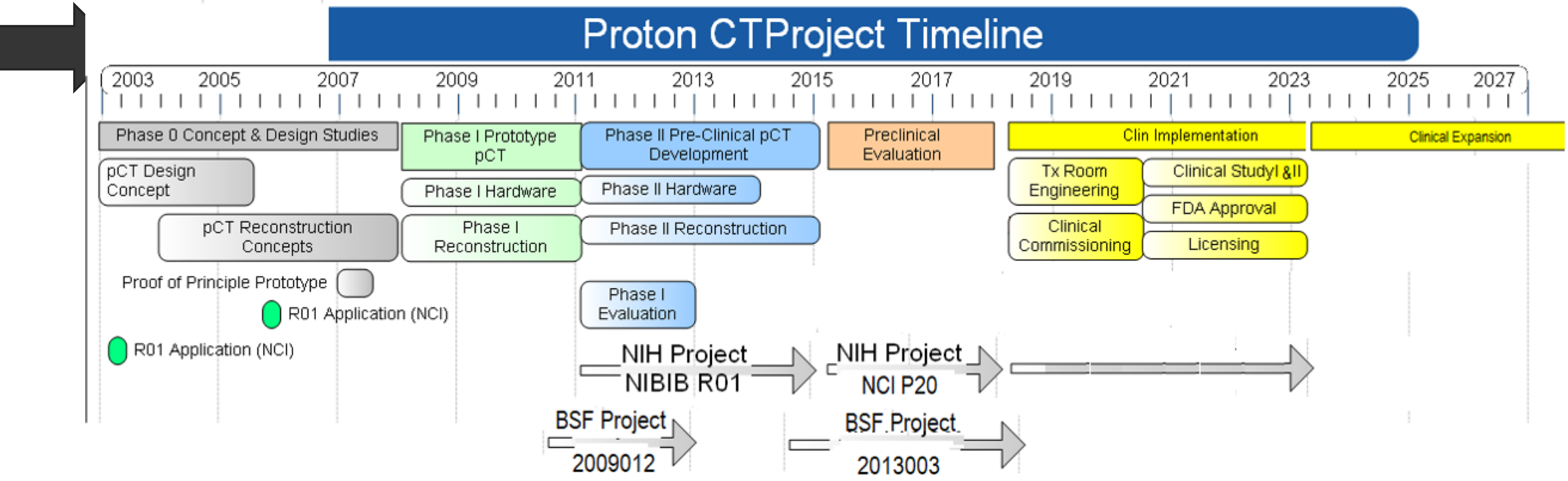
The Status of the pCT Development (Time Line)



The Status of the pCT Development (Functional)

❖ **Detector Technology**

Integrated Mode　　Tracking Mode

Mature technology,

fast & accurate

❖ **Reconstruction**

Transform Methods　　Feasibility Methods

Mature reconstruction,

fast & accurate

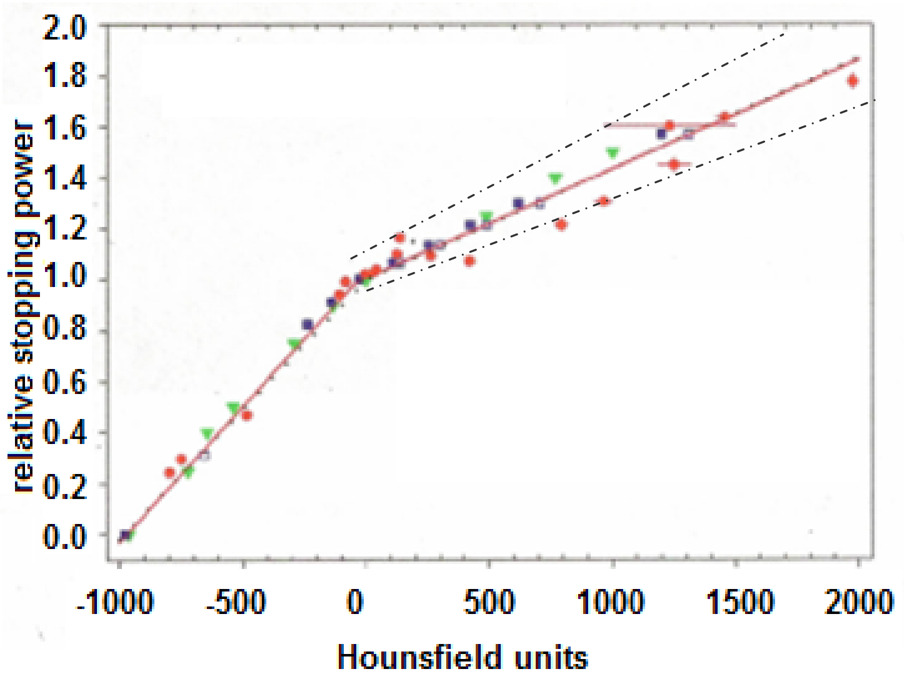
The Status of the pCT Development (Functional)

- **Comparison of Methods**
  - Different modalities (xCT, DECT, MRI etc.)
  - Different technologies (within each modality)
  - Different reconstruction algorithms (within each modality)
  - Which methods always works, or works best for certain indications

- **Clinical Integration**
  - Patient versus gantry rotation
  - Treatment planning versus pre-treatment verification
  - Adaptation in response to imaging
  - Motion management

The Conversion of CT HU Values Creates Uncertainties in Relative Stopping Power

- X-ray attenuation in the 70-120kV range is determined by both photo-electric effect and Compton scattering
- Conversion of Hounsfield units (HU) to relative stopping power (RSP) requires careful, scanner specific calibrations
- There is no consistent one-to-one relationship between Hounsfield units and RSP for different tissues and materials
- The uncertainty in conversion is more pronounced in the higher than water HU range, i.e. for tissues that “create” more range



O. Jäkel, Imaging and Tumor Localization in Ion Beam Therapy, in: Ute Linz (Ed.), Ion Beam Therapy, Springer 2012)

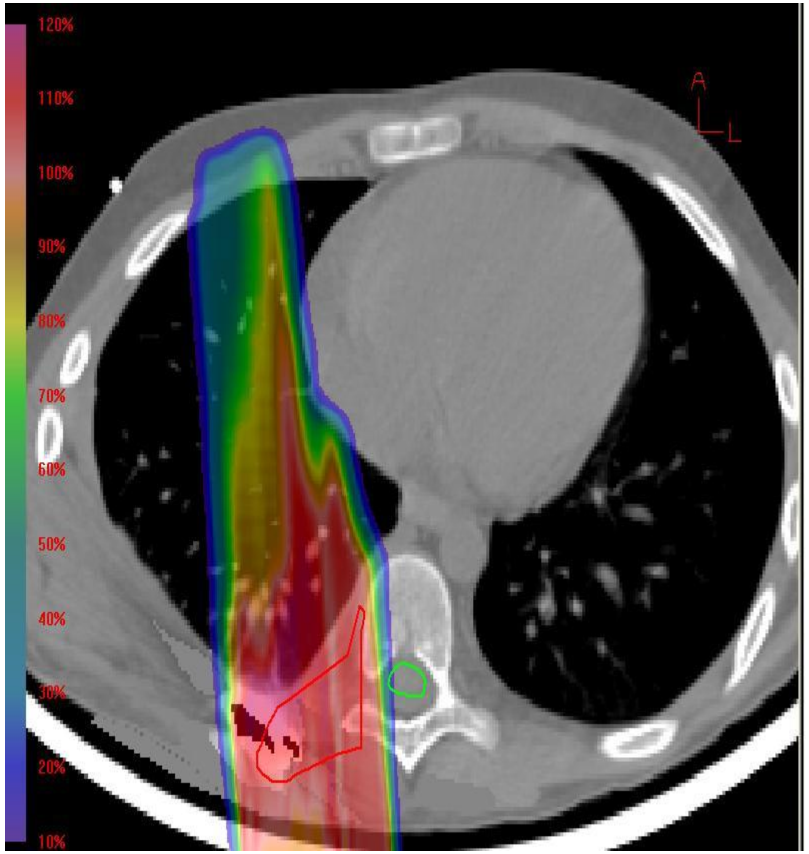
The Problem with x-Ray CT Artifacts

- ❖ X-ray CT is very sensitive to artifacts from high-Z material such as iodine
- ❖ Both high- and low-density artifacts are produced, distorting the HU-RSP conversion
- ❖ The treatment planner needs to reset the artifacts to assumed RSP of surrounding tissues
- ❖ Dental filling is another common source of CT artifacts when planning patients with head and neck tumors

This is a patients with arteriovenous malformation who presented for treatment with proton radiosurgery in a 1-2 fractions. The patient was previously treated with intravascular embolization by injecting contrast enhanced glue into the shunting vesssels.

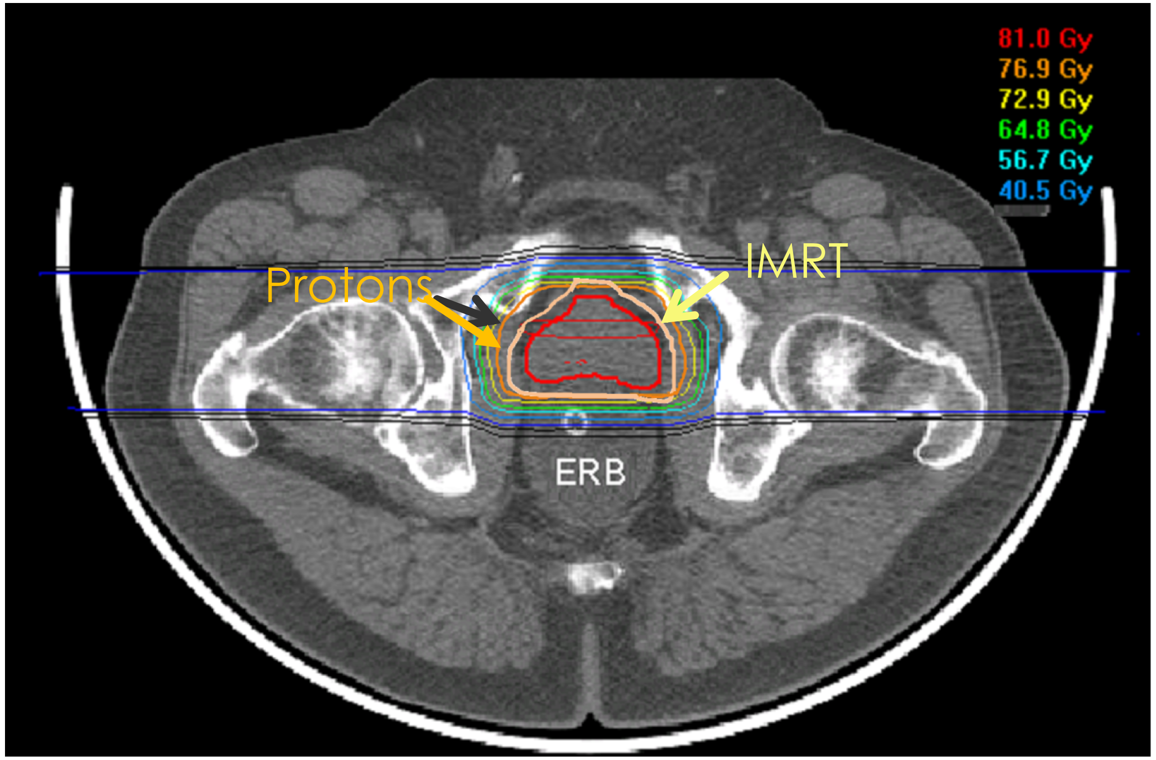
Range Uncertainties are Prevalent

- Range uncertainties forces radiation oncologists to fully expose vertebral bodies of children treated with CSI
- Range uncertainties at soft-tissue lung interfaces cause unwanted dose in lung and heart
- There are many other examples where range uncertainties interfere with treatment planning and delivery
- Range uncertainties are masked by expanding the distal margins of the PTV to 3-5% of the nominal proton beam range (90% of the SOBP flat top dose)



PTV Margins are Wider than in IMRT

- The CTV is expanded in a beam-specific way according to internal motion, set-up error, and distal range uncertainty
- For proton therapy, one avoids range uncertainty when aiming the beam at the posterior rectal wall by choosing two lateral beams that go through pelvic bone.
- This leads to spoiling of lateral penumbra and an unduly large PTV volume in lateral direction which places the distal beam (high RBE) into the neurovascular bundle.



General Outline of a Solution addressing Range Uncertainty

- ❖ A complete solution must address the all causes of range uncertainties, not just one source
- ❖ The first problem that needs to be solved is to replace error prone x-ray CT with a modality that is free from high-density artifacts and ideally measures RSP directly (no conversion)
- ❖ The second problem that needs to be solved is to replace pre-treatment x-ray imaging with a modality that allows fast range checks for each beam on a day-to-day basis with a low-dose imaging modality (pre-treatment range verification)
- ❖ The last problem that needs to be solved to check for range errors during treatment (in vivo dosimetry)

Proton Imaging as a Possible Problem Solution

- ❖ Proton CT (pCT) and proton radiography (pRad) are a promising solutions to the range uncertainty problem, once they have been translated into clinical use
- ❖ Proton CT appears to solve the HU conversion in accuracy problem, while pRad provides a fast pretreatment check of individual beam range with the patient in the treatment position.
- ❖ Both imaging modalities operate with one order of magnitude (at least) lower dose than the corresponding x-ray imaging modalities and are insensitive to high-density artifacts when iterative reconstruction methods are used.
- ❖ HeCT/HeRad provides additional spatial resolution advantage to pCT/pRad but is not generally available except for existing ion therapy facilities (non in the U.S.).

Applications of the proton-CT:

A phantom study

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August 6, 2018

Treatment Planning of a Head Phantom with Dental Implants

Alderson phantom with the insertion of two Ti dental implants located in the maxillary area.

❖Manufacturing an individual mask

❖Scanning the phantom using an X-ray CT

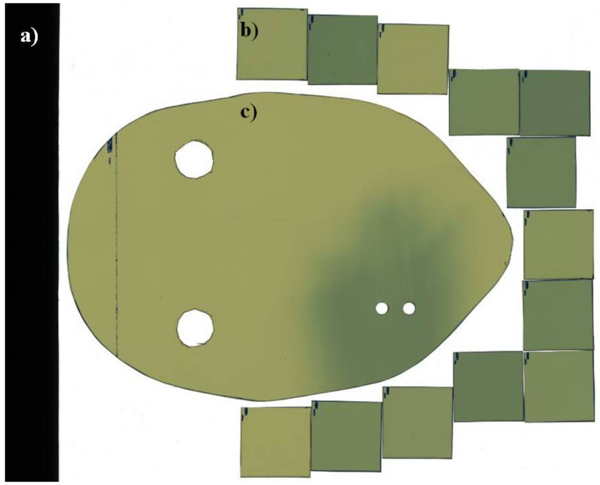
❖Scanning the phantom using experimental Phase II proton-CT

Proton-Based CT

Alderson phantom with Ti dental implants scanned with the Phase II pCT scanner on a horizontal proton beam line at the NMCPC.

- ❖ The head phantom was scanned with the Phase II pCT scanner
- ❖ Both scans were converted to material type and density (pCT based on RSP) and imported into the experimental version of an MC-based planning system
- ❖ Two PTV containing the implants were created and X-ray CT and pCT dose plans were calculated
- ❖ All plans were compared to a radiochromic film doses of the actually delivered plans.

Irradiation of the targets

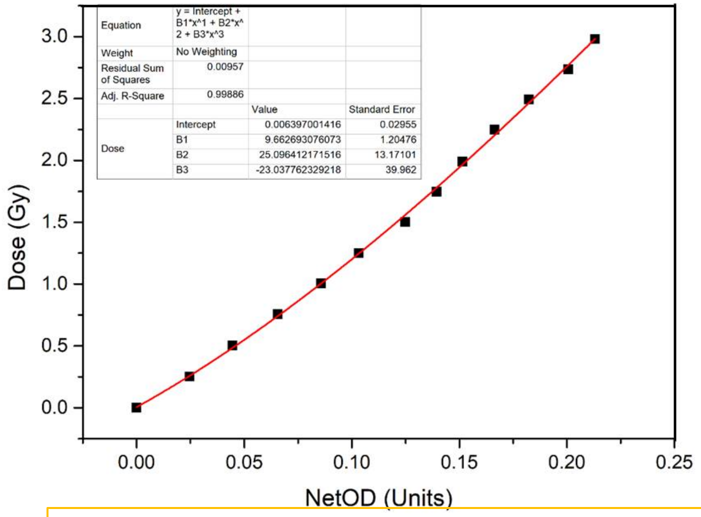


An EBT film scan with calibration films (a) a black opaque cardboard, (b) the 2 x 2 cm films used for calibration and (c) the film cut in the shape of phantom's slices which includes the target.

Digitization

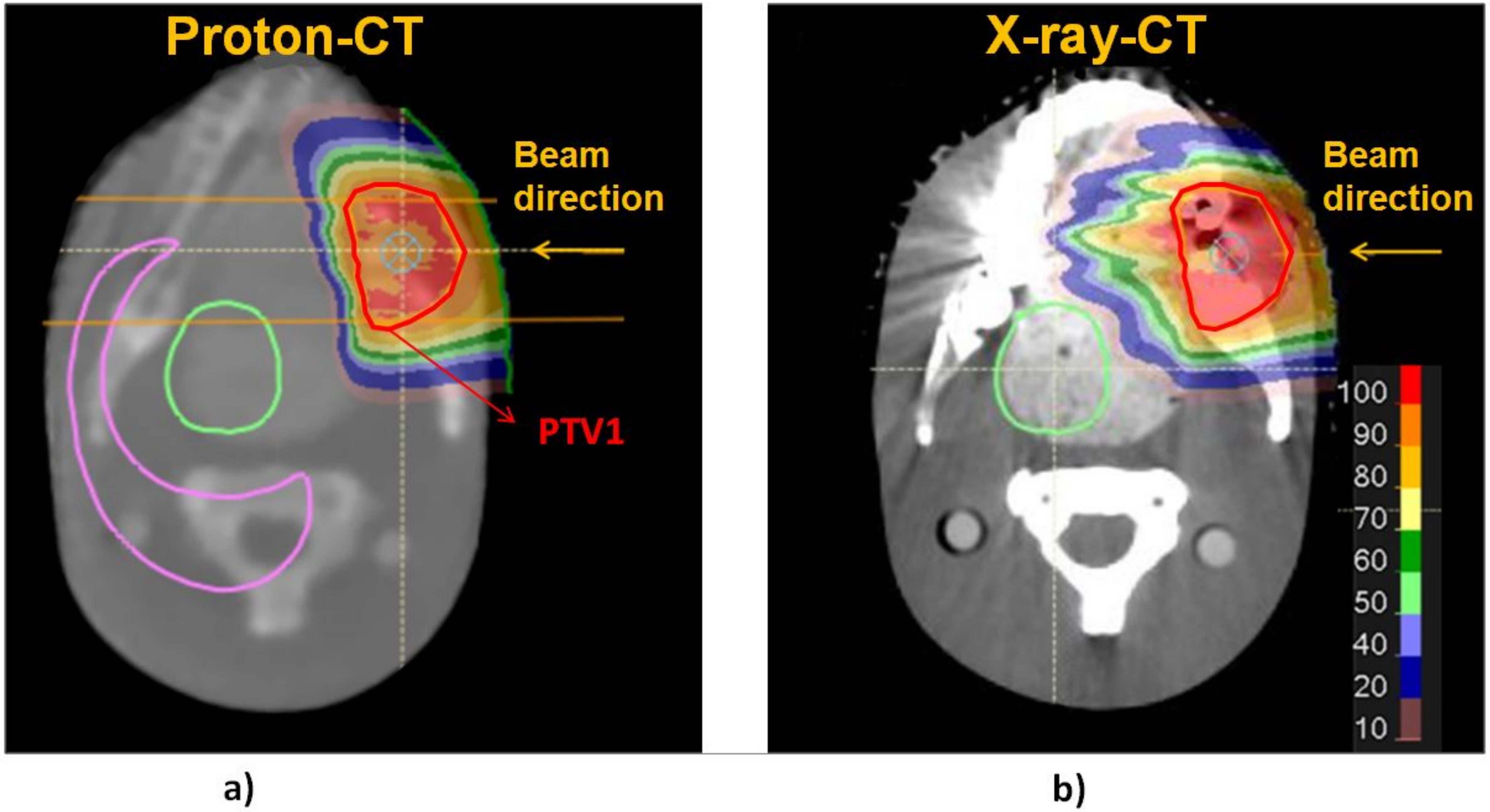
-24h after irradiation
-Red channel extraction
-scanned with an EPSON 11000XL Pro

Linearization of the Response



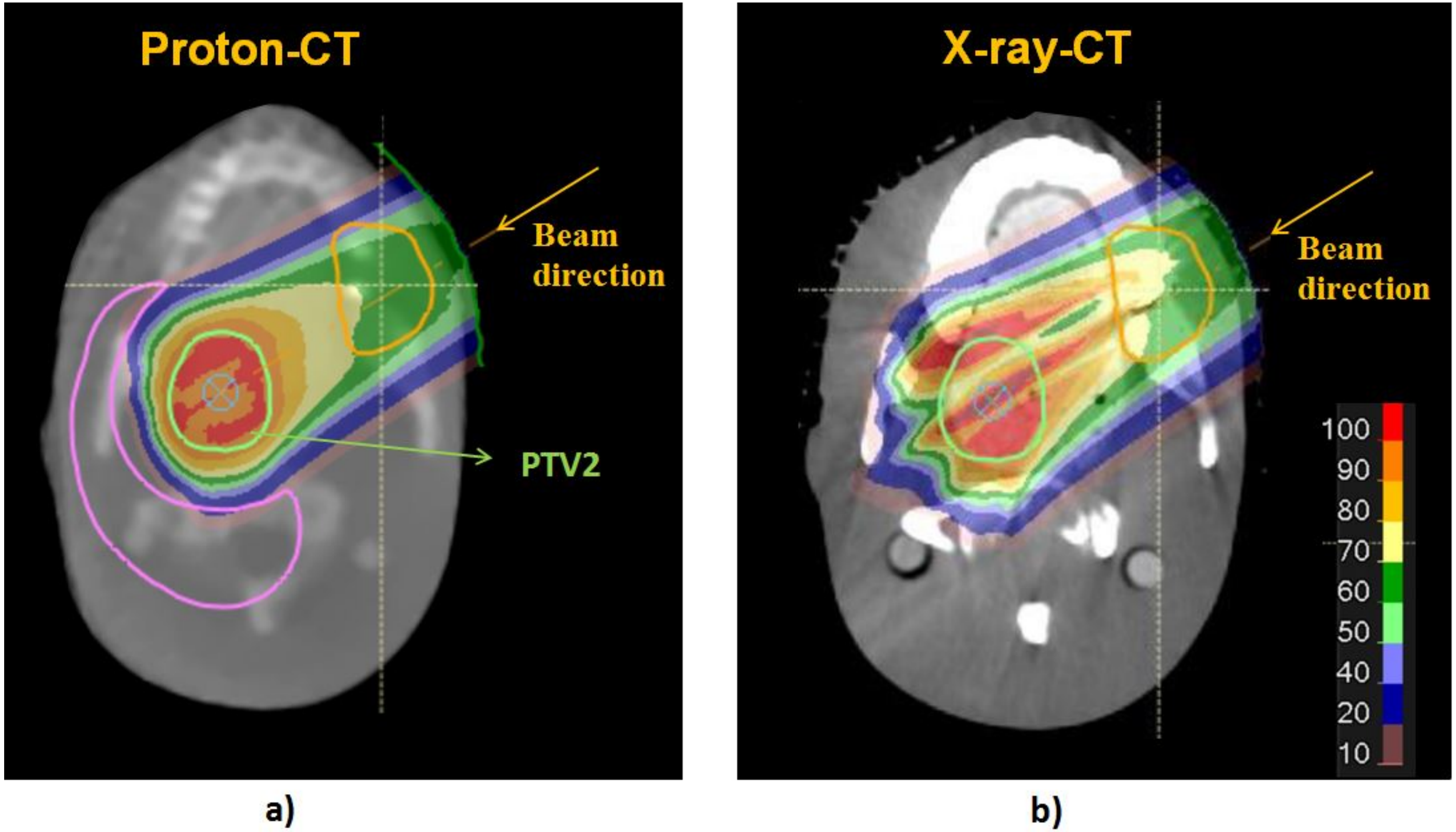
Dose vs NetOD plotted with a 3rd order polynomial.

PTV1 – implants at isocenter

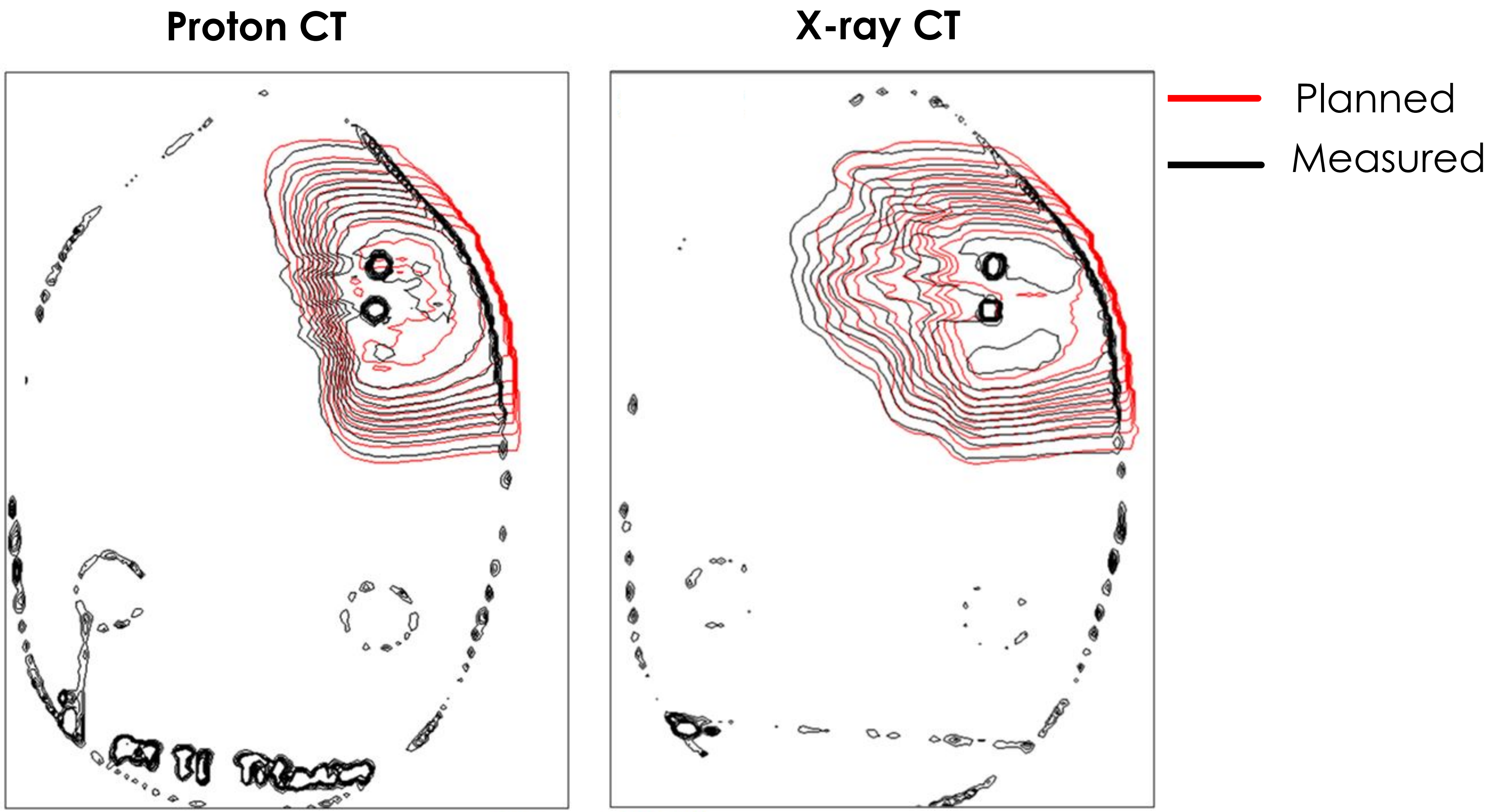


Identical targets were drawn on proton-based CT (a) and X-ray CT scans (b).

PTV2 – Implants at the entrance region of the Bragg curve

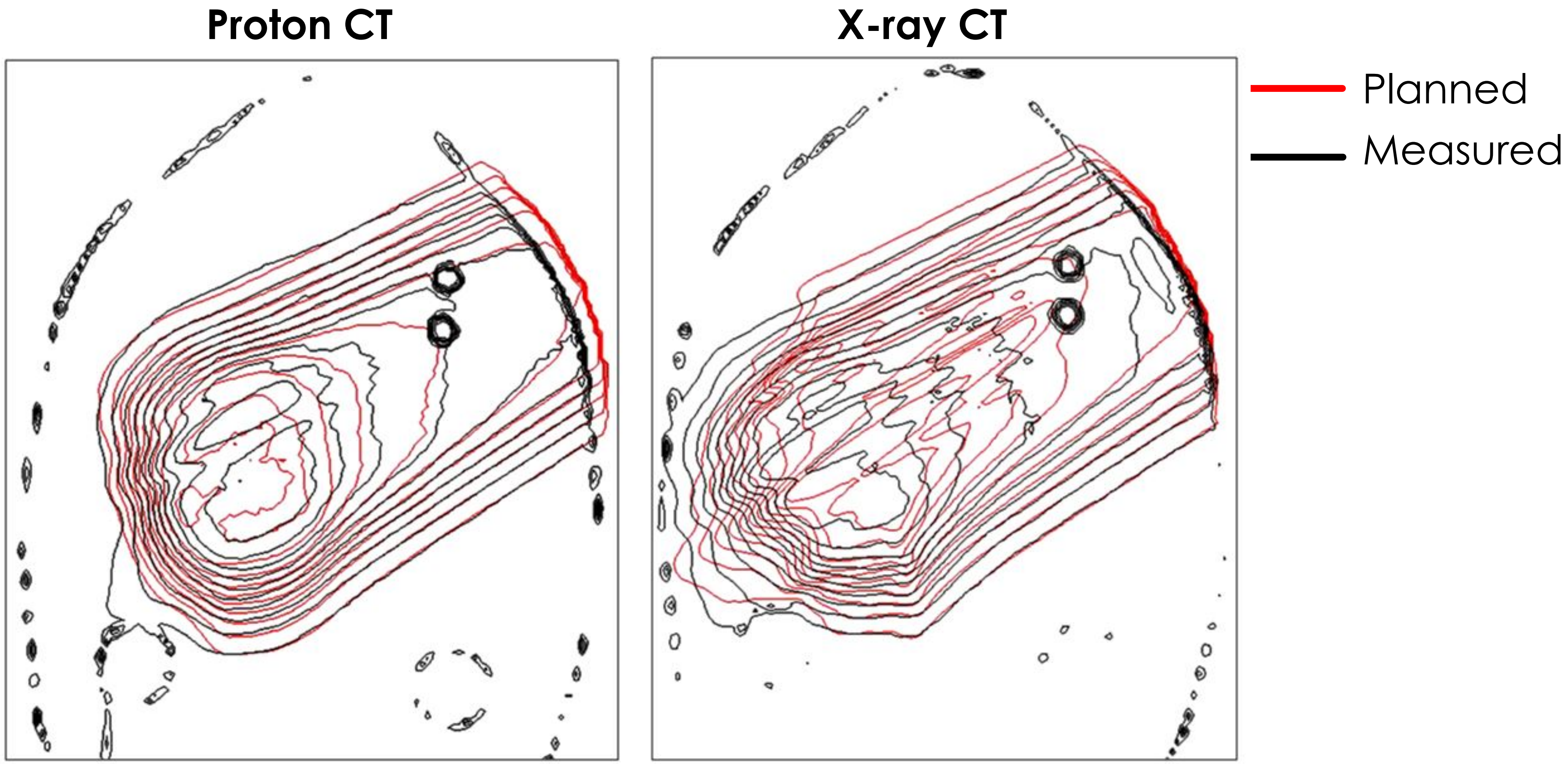


Identical targets were drawn on proton-based CT (a) and X-ray CT scans (b).



Gamma index analysis (3%,3mm) for the PTV1 that contained the implants at isocenter .

Isodose%	30	50	70	90	>90
X-ray CT	59.6	42.2	53.6	83.5	62.0
pCT	90.8	89.8	87.2	96.8	97.6



Gamma index analysis (3%,3mm) for the PTV2 that contained the implants at the entrance region of the SOBP .

Isodose%	30	50	70	90	>90
X-ray CT	81.4	68.8	34.2	42.0	42.4
pCT	95.8	90.4	93.6	82.0	85.2

Conclusions

- X-ray CT leads to a planned DD that does not agree with the actually delivered DD.

- Better agreement between planned/delivered DD was obtained by using pCT for treatment planning.

- Proton treatment planning for targets that contain or are located in the vicinity of dental implants can be delivered with minimal errors when using pCT.